FOREWORD

Transactions of the Society of Mining Engineers, AIME, Volume 241, is composed of the 73 technical papers published during 1968 in the TRANSACTIONS quarterly journal of the Society.

The quarterly journal serves the purpose of distributing the papers soon after they have been approved by the Transactions Publications Committees of the SME Divisions. Each paper has been critically reviewed by three readers and most have been revised according to Publications Committee instructions. The bound volume brings together all papers published during the year, discussions and an index as a permanent record of accomplishments of our Institute and profession.

I take pride in introducing this volume and expressing for the membership at large our esteem for the publications committees, the reviewers and the authors.

December 15, 1968

Raymond H. Feierabend,
Society of Mining Engineers, AIME

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THE ABNORMAL BEHAVIOR OF SOME ORE CONSTITUENTS AND THEIR EFFECT ON BLAST FURNACE OPERATION

by S. Watanabe and M. Yoshinaga

Some iron ores, sinters and pellets occasionally show abnormal behavior during reduction which makes them undesirable as blast furnace burden. These may be divided into the following three types: (1) decrepitation of iron ore, (2) swelling of iron ore and pellet, (3) size degradation of sinter. In this paper reduction experiments and microscopic examinations were made to clarify the mechanisms and causes of these abnormal phenomena. Decrepitation occurs mainly when compact hematite ores containing small amounts of limonite are heated to about 500°C. Abnormal swelling of ores and pellets is caused by the rapid growth of fibrous metallic iron from the surface of wustite grains during rapid reduction and is fundamentally related to their original microstructure. Size degradation of sinter occurs through the development of cracks in the reduction stage from hematite to magnetite.

About 80% of the iron ore used in Japan's blast furnaces comes from abroad, and the iron and steel industry must import this raw material from distant overseas places at high freight rates. The blast furnace operators, therefore, have made strong efforts to cut costs under these restrictive raw materials conditions by increasing productivity and simultaneously decreasing coke consumption. If, however, a high proportion of the ore burden consists of unsuitable materials furnace irregularities often result, establishing the need for detailed investigations of the basic natures of the ore constituents and their reactions during the reduction process.

Recent investigations[1-9] of various ore burdens suggest that some iron ores, sinters and pellets are occasionally abnormal in appearance and behavior during reduction studies and may prove to be undesirable for use in the blast furnace. In the present study reduction experiments and microscopic observations were made to clarify the causes and the mechanisms of the abnormal behavior observed in some constituents of the burden and their effect on blast furnace performance.

S. WATANABE is Senior Research Engineer and M. YOSHINAGA is Research Engineer in the Iron Making Section, Central Research Laboratories, Sumitomo Metal Industries, Ltd., Amagasaki, Japan. TP 67B9. Manuscript, October 25, 1966. This paper was presented at the AIME Annual Meeting, Los Angeles, Calif., February 19-23, 1967. Discussion of this paper, submitted in duplicate prior to June 15, 1968, will appear in SME Transactions, September 1968, and AIME Transactions, 1968, vol. 241.

REDUCING APPARATUS

The four kinds of reducing apparatus used in this investigation were the following:

1. *The JIS* (Modified Gakushin†) apparatus* shown in Fig. 1a is most commonly used in Japan to evaluate the reducibility of ores under static conditions. It consists of a stainless steel tube of 60 mm inside diam suspended from a balance.
2. *Linder's Reduction Test apparatus* (Fig. 1c) has a reducing barrel 130 mm diam and 200 mm long which rotates at 30 rpm. Some modifications were made in test procedures.
3. *Gakushin Standard Test apparatus for determining the reducibility of granular ores* (Fig. 1d) consists of a horizontal silica tube 32 mm diam, 370 mm long and a movable electric furnace which enables rapid heating and cooling of the specimens.
4. *The test apparatus for reduction under load* (Fig. 1b) gives a comprehensive evaluation of the behavior of ores under conditions simulating the static loading and the chemical reduction conditions encountered in a blast furnace stack. A stainless steel tube of 50 mm diam and a carbon rod of 35 mm diam were used as the sample container and the support for the weight, respectively.

In each investigation care was taken to select the most suitable method and apparatus to distinguish the abnormal nature of the ore in question.

SIZE DEGRADATION OF SINTER DURING REDUCTION

Sinter makes up the major portion of the blast furnace burden and its behavior during reduction should bear a close relationship to the iron productivity.

Recently, some of the sinter was found to show serious size degradation during reduction at a relatively low temperature range. Because this phenomenon was thought to be a possible source of furnace irregularities, tests were made to clarify the phenom-

*Japanese Industrial Standard.

†Japan Society for the Promotion of Science.

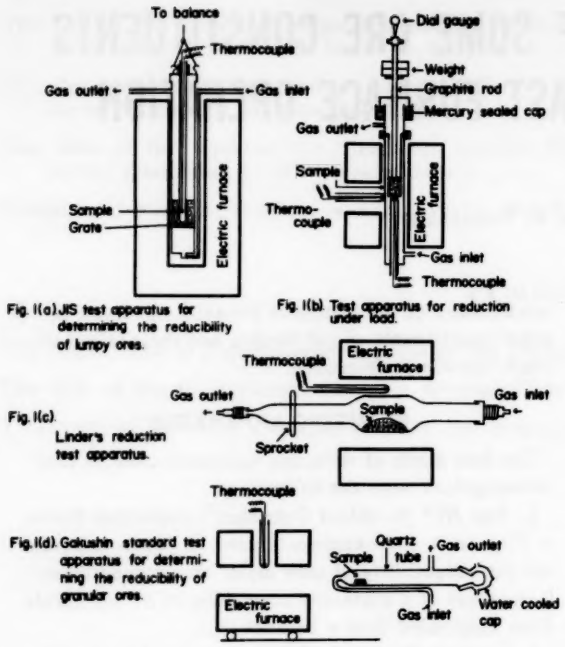

Fig. 1 – The four types of reducing apparatus used in the investigation.

Table I. Chemical compositions of samples (%)

	T.Fe	FeO	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	Mn	P	S	Cu	TiO_2	C.W
Sinter	59.28	10.78	72.77	5.77	1.75	6.49	1.44	0.78	0.121	0.002	0.022	0.705	—
Pellet B	62.12	0.70	88.04	8.80	0.35	0.34	0.41	0.19	0.015	0.014	0.01	—	—
Brazilian hematite ore S	68.23	0.09	97.47	0.74	1.32	0.06	0.02	0.02	0.022	0.002	0.01	0.08	0.96
Australian hematite ore C	57.15	0.61	95.32	1.14	0.58	0.05	0.02	0.02	0.001	0.013	0.01	0.01	2.40
Limonite ore T	56.06	0.56	79.53	4.59	0.90	0.31	—	2.25	0.038	0.041	0.02	—	10.9
Magnetite ore A	59.25	17.38	65.40	7.22	0.90	3.07	—	0.08	0.178	0.025	0.01	—	1.9

Table 2. Gas and temperature conditions in degradation tests by JIS reduction apparatus

Series	Sample	Reducing Gas					Reducing Temperature (°C)	Reducing Time (hr)
		Composition (%)			CO/CO_2	Flow Rate (ℓ/min)		
		H_2	CO	CO_2				
I	Sinter	100	—	—	—	5	400,500	1
	Sinter	100	—	—	—	5	600,700	1/2
	Sinter	—	100	—	—	5	300,500,550 600,700	1
II	Sinter	—	50	50	1.0	5	500	2
	Sinter Ore, Pellet	—	60	40	1.5	5	500	2
	Sinter	—	67	33	2.0	5	500	2
	Sinter	—	80	20	4.0	5	500	2

enon. Table 1 gives the chemical analysis of the pellets and ores tested, and of the sinter samples which were taken from a sintering plant at Sumitomo's Wakayama Works.

The procedure for reduction with JIS apparatus consisted of putting a 300-g sinter sample, sized 20 ± 1 mm, into the JIS reduction test apparatus shown in Fig. 1a. It was reduced with CO or H_2 in the first series of the tests and with mixed gases of CO with CO_2 in the second series, the test conditions being shown in Table 2.

In Series 1 the holding times at the reducing temperature were adjusted so that the same degree of reduction resulted at the same temperature, whether using hydrogen or CO. The sieve analysis of the reduced sinter indicates the degree of degradation, *i.e.*, the percent of the sample weight over 5 mm or 1 mm after the reduction was taken as the degradation index.

Fig. 2 illustrates the wide differences of degradation during reduction with CO or H_2 in relation to the temperature. Sinter shows its minimum resistance to degradation at 500°C, the temperature at which CO deposits C most vigorously, especially in the case of reduction by CO. The tests in Series II using mixed gases of CO and CO_2 were made to determine whether C deposition is a factor of size degradation of sinter during reduction.

The degradation indices as a percent of the +5 mm and the +1 mm sizes of reduced sinter, which in spite of wide differences in CO/CO_2 values show little variation indicate C deposition is not related to the degradation of sinter (Fig. 3). The results of comparative degradation tests (Fig. 4) on sinter, pellets and various ores led to the conclusion that degradation is peculiar to sinter reduction because it was most severe in the sinter sample.

The testing of reduction under load is aimed at progressively checking the degradation and preliminarily investigating the relation between sinter strength and degradation. Experimental sinters were made in the laboratory pan to give samples having a wide range in strength with the fairly constant basicity (CaO/

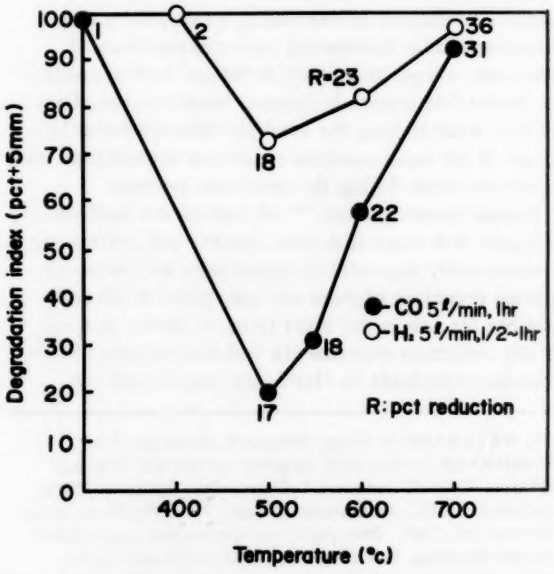

Fig. 2 – Degradation of sinter by reduction at different temperatures.

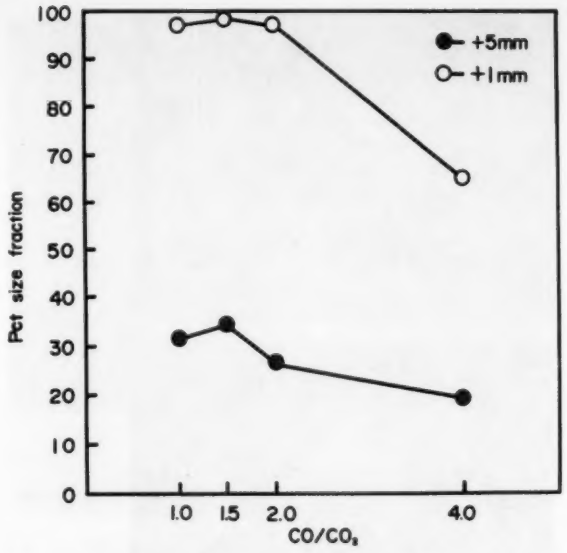

Fig. 3 – Degradation of sinters reduced at 500°C for 2 hr with gases of different ratios of CO to CO_2.

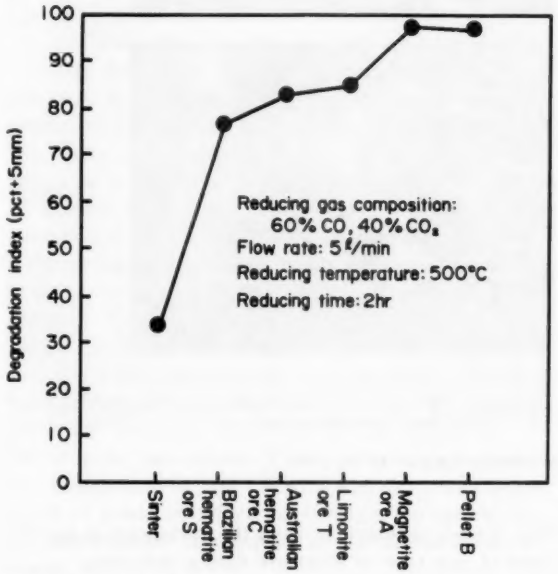

Fig. 4 – Size degradation of sinter, pellets and ores.

SiO_2) of 1.2. The strength of these sinters was ascertained by one of the following methods, depending on the quantity of sample material available.

(1) *JIS Drop Shatter Test Method for Sinter:* A 20 kg sample of +10 mm material was dropped four times from a height of 2 m onto an iron plate, after which the material was screened on 10 mm mesh. Shatter Index (S.I.) is determined as follows:

$$\text{S.I.} = \frac{\text{Weight of the sample retained on 10 mm screen (g)}}{\text{Initial Weight of the sample (g)}} \times 100\,(\%)$$

(2) *Drum Test Method for Sinter:* A 500 g sample sized 10 to 15 mm is placed in a drum 500 mm diam and 500 mm long in which two angle lifters of 50 × 50 × 3 mm are riveted lengthwise. After rotating the drum at 25 rpm for 2 min, the sample is taken out and sieved on a 10 mm screen. Drum Index (D.I.) is determined as follows:

$$\text{D.I.} = \frac{\text{Weight of the sample retained on 10 mm screen (g)}}{\text{Initial weight of the sample (g)}} \times 100\,(\%)$$

Reduction tests under a load of 2 kg per sq cm were performed by placing 500 grams of sample sized 10 to 15 mm in the reaction tube shown in Fig. 1 b, heated to 300°C in N_2 atmosphere. The reducing gas composed of 30% CO and 70% N_2 was introduced into the system at a rate of 15 liters per min which has a heating rate of 300°C per hour and was switched off when the temperature reached 1200°C. Elongation and contraction of the sample column, taken from the dial gauge readings, were corrected against the blank value and were calculated as the percent elongation or contraction for the initial column height of about 180 mm in a 50 mm diam tube.

Results are given in Fig. 5. Affixed figures of the contraction curves give the drum indices (D.I.) of the sinters. Weak sinter shows more severe collapse than

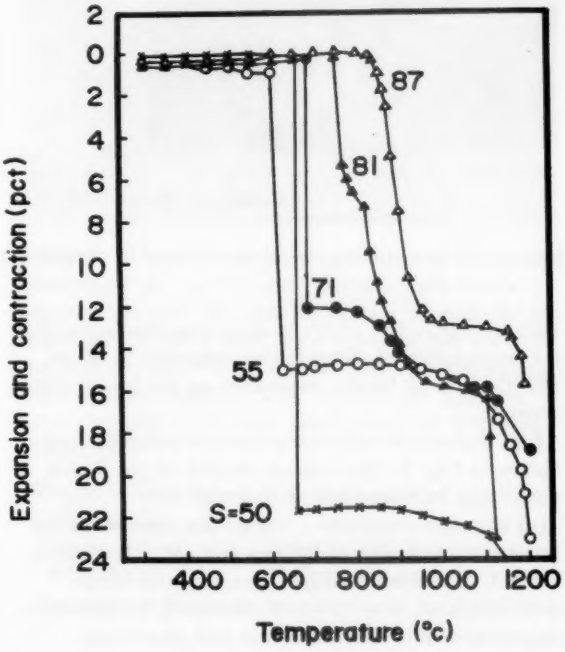

Fig. 5 – Contraction curves of sinters showing the results of reduction tests in the reaction tube under a load of 2 kg per sq cm. Reducing gas was 30% CO and 70% N_2; flow rate, 15 liters per min; and heating rate, 300°C per hr. Figures beside curves give the drum indices.

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